

**A REPORT TO BATH IRON WORKS CORPORATION
ON
SHIP PRODUCIBILITY AS IT RELATES TO
SERIES PRODUCTION**

**VOLUME I
SUMMARY OF RESEARCH REPORT**



INGALLS SHIPBUILDING
P.O. Box 149 Pascagoula Mississippi 39567

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VOLUME I

PART 1

INTRODUCTION

SECTION 1

INTRODUCTION

1.1 General Information

This is the final report of a study entitled "Series Production as it Relates to Ship Producibility" which was performed by Ingalls Shipbuilding Division of Litton Systems, Inc. as part of the Ship Producibility Program sponsored by the Maritime Administration and administered by Bath Iron Works, Inc.

The study presents the results of two tasks which form a part of the total program.

Task O-1 Ship Producibility as it Relates to Series Production

Task P-1 Simplified Hull Forms

The objective of the study was to analyze those aspects of the ship design and of the ship production process which affect or are affected by series production, and to identify those areas which are most sensitive to the optimization of a series ship construction program.

The report is divided into three volumes as follows:

Volume 1 - Executive Summary

Volume 2 - Ship Design Process

The Volume 1 Summary contains a description of the scope of the study and the technical approach employed in its accomplishment. This volume also contains a summary of the findings developed in the individual studies, and a comprehensive set of conclusions and recommendations.

VOLUME I

PART 2

APPROACH

VOLUME I

PART 2

2.1 APPROACH (Scope and Objectives)

The scope of the study included the major aspects of commercial ship design and production which can be oriented to enhance the concept of series production and to minimize construction cost and construction schedule. The objective was to investigate these areas so as to quantify, where possible, potential savings in dollars and time.

Obviously, an investigation of this nature is most meaningful when it is performed for a specific ship, with its peculiar design features and construction demands.

It must be emphasized that the intent of the study, and of this report, was to identify and evaluate areas of ship design and production that could be oriented to enhance series production. Clearly each shipyard must evaluate the discussions contained herein in the light of its own capabilities and its own candidate ship programs. It is envisioned that each shipyard will perform its own studies, using the studies contained herein as a model.

2.2 Methodology

In formulating the approach to the study, it was necessary to reduce the scope of the study down to a number of discrete manageable tasks.

To accomplish this, a matrix was developed which identified the major elements of the product and the production process on one axis and the management tools which effect these areas on the other axis. (See Figures 2-1 and 2-2).

TOOLS		PRODUCTION PROCESS										PRODUCT																																		
		CONCEPTUAL AND CONTRACT DESIGN	DETAILED DESIGN	MATERIAL PROCUREMENT	CONSTRUCTION STD'S & INSPECTION REQM'TS	PRODUCTION PLANNING	LOFTING & NUMERICAL CONTROL	FABRICATION	ASSEMBLY	ERECTION	OUTFIT	TEST, TRIAL & ACCEPTANCE		MAIN HULL	DECKS & FLATS	BULKHEADS	FOUNDATIONS	SUPERSTRUCTURE	MASTS & FUNNELS	CASTINGS	DOORS, WINDOWS & HATCHES	LADDER, GRATINGS & STANCHIONS	JOINER BULKHEADS	DOORS AND FURNISHINGS	WORKSHOP EQUIPMENT	AND STORES	PROT CTGS, DK	COVERINGS & INSUL	MAIN PROPULSION MACHINERY	AUXILIARY MCHY PUMPS, GENERATORS, ETC	DECK MACHINERY	PROPELLER RUDDER AND SHAFTINGS	PIPING	ELECTRICAL MACHINERY	ELECTRICAL SUPPORT EQUIPMENT	NAVIGATION & CONTROL EQUIPMENT	LIGHTING EQUIPMENT	ELECTRICAL CABLE	VENTILATION MACHINERY	VENTILATION DUCTING	BUYER FURNISHED EQUIPT.					
MANAGEMENT	MATERIAL IDENTIFICATION & CONTROL																																													
	MANPOWER ALLOCATION & CONTROL																																													
	COST ALLOCATION & CONTROL																																													
	FACILITY ALLOCATION & CONTROL																																													
	INSTRUCTIONS																																													
	TRAINING																																													
	CHANGE CONTROL																																													
	MAKE OR BUY																																													
PRODUCTION	CRANES & OTHER HEAVY EQUIP																																													
	PRODUCTION AREAS & SHOPS																																													
	MANPOWER																																													
	JIGS & FIXTURES																																													
	WORK STATIONS																																													
	HAND & PORTABLE TOOLS																																													
	MACHINES																																													
	TRANSPORTATION																																													
	UTILITIES																																													

Figure 2-1. Original Matrix - 144 Candidate Areas Of Investigation

		TOOLS	PRODUCTION PROCESS										PRODUCT							
			SOFTWARE PROCESS						HARDWARE PROCESS				HARDWARE PRODUCTS							
			A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	
			CONCEPTUAL & CONTRACT DESIGN DETAILED DESIGN MATERIAL PROCUREMENT CONSTRUCTION STDS & INSPECTION PRODUCTION PLANNING & CONTROL LOFTING & N/C FABRICATION ASSEMBLY ERECTION OUTFIT										HULL STRUCTURAL ASSEMBLIES SUPERSTRUCTURE FOUNDATIONS SYSTEMS (PIPING, ELEC & VENT) MACHINERY OUTFIT PROTECTIVE COATINGS, INSL ^{TN} ETC.							
1	MANAGEMENT	MATERIAL IDENTIFICATION & CONTROL																		
2		INSTRUCTIONS																		
3		FACILITY UTILIZATION																		
4	PRODUCTION	PRODUCTION AREAS & SHOPS																		
5		JIGS & FIXTURES																		
6		CRANES & HEAVY EQUIP																		
7		WORK STATIONS																		
8		MACHINES																		

Figure 2-2. Final Matrix Of Areas Accepted For Study

This matrix was then analyzed and areas which were inter-related were identified. Utilizing this matrix as a basis, seven engineering design areas and eight production topics were selected as being most representative of areas which effect or are effected by series production:

<u>Engineering/Design</u>	<u>Production</u>
1. Midship Section Configuration	1. Facility Utilization
2. Containerized Cabins	2. Production Areas and Shops
3. Constant Principle Dimension	3. Work Stations
4. Machinery System Modules	4. Production Planning
5. Structural Member Configuration	5. Material Planning
6. Simplified Hull Forms	6. Cranes and Heavy Equipment
7. Instructions	7. Oigs and Fixtures
	3. Machines

The technical approach for investigating these areas was formulated as shown in Figure 2-3, which shows the discrete tasks which were outlined for accomplishment.

The ship selected for development in the engineering studies was a 150,000 DWT tanker which conformed to the IMCO regulations. The midship sections developed during the course of the study were utilized as a basis for comparing single ship production with series ship production.

In January of 1975 a mid-term presentation was made to representatives of six major shipyards. The resulting comments, suggestions and constructive criticisms were formulated into specific task assignments which re-directed the study to a certain extent, and these items were incorporated where practical, and as directed by the Bath Iron Works administrators of the program.

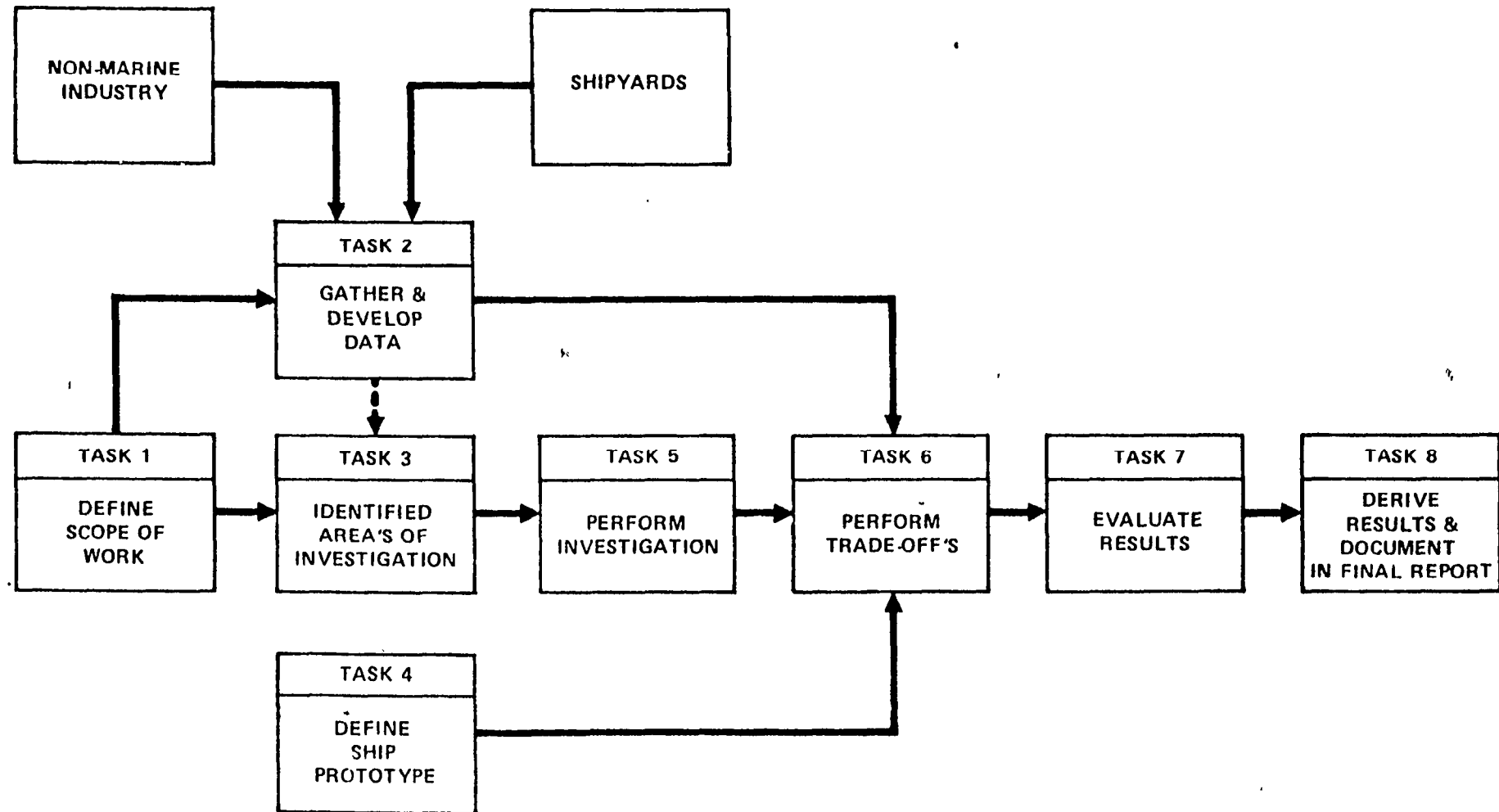


Figure 2-3. Identification Of Study Tasks

VOLUME I

PART 3

SUMMARY OF INDIVIDUAL INVESTIGATIONS

VOLUME I

PART 3

SUMMARY OF INDIVIDUAL INVESTIGATIONS

3.1 Introduction

The seven engineering topics selected are summarized in subsequent sections under the following subtitles:

- Midship Section Configuration
- Containerized Cabins
- Constant Principal Dimensions
- Machinery Systems Modules/Packaging
- Structural Member Configuration
- Simplified Hull Forms
- Instructions

The eight production topics selected are summarized in subsequent sections under the following subtitles:

- Facility Utilization
- Production Areas and Shops
- Work Stations
- Production Planning
- Material Planning
- Cranes and Heavy Equipment
- Jigs and Fixtures
- Machines

These sections are summaries of material developed more fully in Volume II Ship Design and Volume III Ship Production.

3.2 Ship Design Process

3.2.1 Midship Section Configuration

3.2.1.1 Approach - A large number (14) of midship sections were considered as possible variants. Six of the fourteen here chosen as being of current interest.

- a. Scope - Six sections were developed for analysis, in accordance with the IMCO rules.

The six sections are described as follows:

Section No. 1 - Configuration A-A

Typical centerline and wing tank configuration with web frames made of stiffened plate.

Section No. 2 - Configuration A-6

Configuration similar to Section No. 1 with web frames made of built up girders and brackets in lieu of stiffened plate.

Section No. 3 - Configuration B-A

Centerline and wing tank configuration with innerbottom extending the full beam of the ship. Web frames are built from stiffened plate.

Section No. 4 - Configuration B-B

Configuration similar to Section No. 3 with web frames built of girders and brackets.

Section No. 5 - Configuration C-A

Section with full depth wing tanks and a centerline tank which incorporates a centerline innerbottom.

Section No. 6 - Configuration D-A

Complete double skin ship with double sides and bottom, created by a centerline longitudinal bulkhead.

- b. Constraints - The midship sections, as developed, were constrained by the 160 foot beam chosen, and the 74 foot depth, as well as by the IMCO rules on segregated ballast, draft and trim.
- c. Analysis - Each midship section was divided into assemblies of approximately 200 tons on the basis of fabrication and erection considerations.

In order to compare the candidate sections, four characteristics were analyzed in detail:

1. Weight (Material Cost)
2. Ease of Fabrication
3. Ease of Erection
4. Coatings Requirements

3.2.1.2 Findings

Summary of Comparison

In summarizing the individual characteristics as previously outlined, the additional cost factors were combined for each configuration with the following results:

Configuration	Material Penalty	Fabrication Penalty	Erection Penalty	Coatings Penalty	Total Penalty
A-A	0	0	36,720	0	36,720
A-B	306,000	162,000	54,432	55,501	577,933
B-A	1,578,960	835,920	93,744	187,199	2,695,823
C-A	1,064,880	563,760	0	25,354	1,653,994
D-A	1,321,920	699,840	128,304	250,918	2,400,982

By re-arranging the ranking in terms of increased total cost, the configurations fall in the following order:

Configuration	Total Additional Cost Over Lowest	2 Ships	3 Ships	4 Ships
A-A	0	0	0	0
A-B	541,213	1,082,426	1,623,639	2,164,852
C-A	1,617,274	3,234,548	4,851,822	6,469,096
D-A	2,364,262	4,728,524	7,092,786	9,457,048
B-A	2,659,103	5,318,206	7,977,309	10,636,412

3.2.1.3 Conclusions

The basic section A-A is the lowest cost configuration in the comparison, even though the bracketed section had appeared to show potential savings in production and erection early in the study.

The relative costs of configuration C-A would indicate that the addition of a tank top as required to create a centerline double-bottom can be accomplished with minimum additional cost.

It does not appear that any of the double-bottom sections are competitive, and that this approach will only be adopted if required by regulatory bodies.

While the initial intent of the double bottom is to prevent oil spillage as a result of grounding, the advantage is off-set by the problems of oil leakage into the dedicated ballast spaces in the double bottom and the associated explosion hazard which this condition creates.

With a double-bottom empty while the ship is loaded, stability is **reduced and the ship would react adversely in the event of** symmetrical damage.

As a result of the combined effects of these factors, it is expected that midship sections similar to the basic (A-A and A-B) configuration will receive first consideration in future applications, particularly in the absence of specific regulatory requirements or specific owner requirements for other configurations.

3.2.2 Containerized Cabins

3.2.2.1 Approach

An investigation into the possible advantages of constructing the superstructure of an array of containerized cabin modules was initiated.

Scope - The design considerations to be applied were identified and a preliminary trade-off comparison was defined based upon work done elsewhere.

3.2.2.2 Direction, Mid-Term Review

It was the consensus of the review group that effort planned to be spent in completing this study should be re-channeled into other areas of the program adjudged to yield more data directly applicable to high priority series production problems of tankers.

3.2.3 Constant Principal Dimensions

3.2.3.1 Approach

- a. Study the feasibility of expandable ships. Coursary examination eliminated all but length variations as unattractive.
- b. Constraints - Practical considerations of variation at each dimension were examined in the light of (1) a standard machinery compartment, and (2) maximum standardization of structural features. Economics was the main constraint; both acquisition and operation.
- c. Analysis - Parametric analyses were performed by Hydronautics, Inc. , under subcontract to Ingalls. Hydronautics used its computer program to explore tankers of various dimensions with displacements varying between 120,000 and 180,000 DW tons. First a region of economically feasible tankers around 150,000 tons was defined with near optimum proportions for the speed range and draft limitation of 51 feet. Then further evaluations were made of several ships "stretched" to 180,000 tons and "shrunk" to 120,000 tons. A parent was found which produced an acceptable stretched or shrunken derivative, and it was finally defined.

3.2.3.2 Findings

Ships of 160 foot beam, 74 foot depth yielded a satisfactory 3 ship series:

Deadweight	120,000	153,900	175,500
Length	900 ft.	925 ft.	1,050 ft.
Draft	48 ft.	51 ft.	51 ft.
Speed	17.0 Knots	16.3	15.7
RFR, 2500 mile	1.9619	1.6729	1.6079
Voyage, mils/ton mile			
Capital Costs, \$/DwT	469.56	410.01	407.82

All ships required 33,000 SHP for the speeds quoted.

3.2.3.3 Conclusions

A near optimum ship can be selected which will permit acceptable stretch/shrink derivatives of about 1 cargo tank increase or decrease in length. Such a ship is not quite optimum for 150,000 tons dwtt and is farther from optimum in the stretched or shrunk configurations.

In an environment where first cost dominates over fuel costs in the life cycle cost computation, a standard design, "stretched" or "shrunk" may be attractive. However, at the time of writing fuel costs are rising as fast or faster than construction costs. In this latter environment, there is some doubt that ships at either end of the size range (180,000 and 120,000 tons) would be competitive with designs optimized for these deadweights. This opinion was also the consensus of the "mid-term" review group.

3.2.4 MACHINERY SYSTEMS MODULES/PACKAGING

3.2.4.1 Approach

This part of the study was directed toward determining the feasibility of designing and arrangement for the main propulsion

plant and supporting system equipment for a standard stern module of a 150,000 DWT crude carrier which would achieve the following objectives:

Arrangements and locations within the module, selected for the main propulsion machinery and support systems equipment to be common for any one of the four main propulsion systems with the locations and arrangements for the machinery components to be such that minimum, if any, hull structure alterations are required when any of the main propulsion plants are installed in the module.

For the purpose of promoting series production pre-outfitting of assemblies, the selected locations and arrangements of support system equipment (feed pumps, pre-heaters, piping arrangements) will be correlated to the assembly configuration established for hull design erection.

- a. Scope - Four different types of propulsion systems were selected to evaluate in terms of their degree of meeting the objectives set forth above. or selection for the propulsion plants used in this study was based largely on the following criteria:

Plant is existing and representative of its type;

1 Manufactured in U.S.A.;

1 25,000 Shaft Horsepower (SHP)

The propulsion plants selected were:

Steam Turbine -

Manufacturer - Westinghouse Corporation

Type - High Speed, Compound High Pressure and Low Pressure

Medium Speed Diesel -

Manufacture - Colt Pielstick

Type - 18 Cylinders, "V"

Light Weight Gas Turbine

Manufacture - Pratt-Whitney

Type - FT 9

Heavy Duty Gas Turbine

Manufacturer - General Electric

Type - Model NM 50002R-B, Frame 5 Regenerative

Additionally, for the purpose of this study, each similar auxiliary machinery package has been located in the same general area within the stern module for each type of main propulsion equipment.

These machinery packages are identified as primary machinery supporting components purchased from a vendor and include the designed installation, interface piping, controls, wiring, foundations, etc., to be provided by the vendor. Each component with application to another unit, is purchased by specifications that provide for package integration into the machinery module with minimum installation work being performed by the shipyard.

- b. Constraints - The following special considerations were taken into account in designing the baseline machinery arrangements that were developed.

Propeller shaft removal and accessibility:

Maintainability of equipment;

1

Lifting and removal of equipment components;

Location of engine room control center for accessibility;

Main engine and gear box foundations.

Special emphasis was directed toward coordinating machinery component arrangements with piping design so that the pipe fitting work required to interface an auxiliary system between two different assemblies will be kept to a minimum, so as to minimize the number of piping field joints to be made.

3.2.4.2 Findings

It was determined that the objectives could be met. Four baseline machinery arrangements were developed using the modified scow stern as the standard stern module. Standardization of the layout of the four plants was achieved in the following areas:

1. A common overall length of machinery space.
- 2* Common main machinery flat heights above baseline.
3. Common location of main fuel tanks.
4. Common location of main access hatches and ladders.
5. Common main propulsion shafting height.
6. Standard propeller shaft length.
7. Standard stern tube length.
8. Line shaft bearings, located in, the same relative position in all four arrangements.
9. Main propulsion reduction gears were located in the same relative position in all four arrangements.

10. Auxiliary machinery system packages were located in the same relative position within the standard stern module.
11. The foundations for the four selected main propulsion plants installed in the modified scow stern will be designed as an integral part of the basic hull structure and will be different for each type plant.

In addition, auxiliary arrangements were featured in which:

1. Auxiliary machinery components can be assembled in the shop with the completed machinery packages pre-outfitted and thoroughly checked, and tested.
2. Shop assembly allows more flexibility in scheduling the workload.

Some production advantages occurring from these design features are:

1. Machinery packaging will reduce the number of shipboard installed piping runs.
2. Allows many of the outfitting crafts to pre-cutfit the structural assemblies prior to stern module erection.
3. Pre-outfitting of the machinery space will result in the overall cost saving.

In order to achieve the above benefits there must be an emphasis on advanced planning. The engineering departments would be required to spend more time in the concept design phase than has been done in the past. Extensive liaison between the departments would also be required to provide the best design methods of installation and

construction within the building capabilities of a particular shipyard to gain the maximum benefits of standardization.

3.2.4.3 Conclusions

1. The Shipbuilder should develop and establish standard machinery arrangements covering a range of power plants and types of power plants suitable for installation in standard machinery space modules for many types of commercial ships capable of being built in U. S. shipyards.
2. Establish standard pre-outfitting machinery modular units capable of being installed on structural assemblies within the stern module, including design details and installation data.
3. Recommend that an in-depth study be carried out to establish hull structural configurations and designs, in conjunction with machinery installation requirements and machinery space outfitting with particular reference to the modified scow stern used in this study.

3.2.5 Structural Member Configuration

3.2.5.1 Approach

A large quantity of shell and deck longitudinal stiffening and bulkhead stiffening is present in a 150,000 ton tanker. Methods of achieving economies in these sections were investigated. In accomplishing this task, the approach developed was as follows:

Using the 150,000 DWT tanker as a basis, develop the structural member configurations as required to comply with the A.B.S. regulations regarding the required section modulus.

Using the conventional members developed in step (a) as a base, investigate alternate members with equivalent characteristics.

Compare alternate members with conventional, and evaluate differences, including production considerations.

Develop conclusions and recommendations.

- a. Scope - The candidate members which were selected for comparison are:

1. Structural "T"
2. Built-Up Shape
3. Built Plate
4. Plate Web with Round Bar
5. Flanged Plate

The material and production costs were developed for each of these sections, with the impact of a series production contract included in the fiscal analysis.

- b. Constraints - In order to properly develop the required sizes for the respective structural members, a mid-ship section was designed in accordance with the A.B.S. regulations regarding minimum section modulus. This mid-ship section utilizes "conventional" structural members as would be procured from a U. S. steel mill.
- c. Analysis - Using the size and section modulus of these structural members as a basis, the following variations were chosen as

suitable candidates for evaluation, and thus equivalent sizes were developed for comparison purposes:

1. Built-up Shape - Weldment of two separate thicknesses of plate as required to form angle.
2. Bulbous Plate - Specially formed offset available from foreign mills only.
3. Built-up Offset - Weldment of a plate web and a round bar offset.
4. Flanged Plate - Formed plate as required to form (flanged) angle.

3.2.5.2 Findings

Summary of Cost Comparison - Large Members

Multiple	Series Production Stripping Method Unit Cost	Unit Savings	Series Production Beam Welding (Unit Cost)	Unit Savings	Single Ship Semi- Automatic Stripping (Unit Cost)
14"	292.68	53.56	249.67	96.77	346.44
16"	488.72	53.56	393.40	159.88	542.28
27"	847.76	53.56	633.69	267.63	901.32
30"	896.72	53.56	734.79	215.49	950.28

The savings indicated for series ship production are projected as follows for the total 576 ft mid-ship section:

a. Tee Beam Welder

Size	Total Linear Feed	No. of Units	Savings Per Unit	Total Savings
14"	9,216	192	96.77	18,579.84
16"	32,256	672	158.88	106,767.36
27"	27,648	576	267.63	154,154.86
30"	32,256	672	215.49	144,509.28
				424,311.36

b. Series Production - Multiple Stripping

Total Linear Feed = 101,376
Savings per 45 ft unit = 53.65
Savings per linear foot = 1.11
Savings per ship = 112,527.36

3.2.5.3 Conclusions

- The structural member configuration represents a significant area of potential for cost avoidance in series production.
- In the smaller size range, there is no practical substitute for the sections currently available from U.S. steel mills.
- In the larger size range, the use of an automated T-beam welder is the preferred method for fabricating steel structural shapes. Custom developed systems of a similar nature would produce similar benefits.

- d. The net cost of any stripping operation will vary, depending on the revenues received from the sale of scrap material and the associated material handling costs.
- e. At the present time there are no structural members readily available from domestic steel mills which are satisfactory for use in the construction of a 150,000 DWT tanker.
- f. Development of a "set" of domestically available structural shapes which could be utilized in commercial shipbuilding, would be a worthwhile subject for future study.

3.2.6 SIMPLIFIED HULL FORMS

3.7.6.1 Approach

The recent trend in low speed-length ratio bulk carrier hulls has been to initially begin with a rather simple hull form. Few areas remain to be examined other than the following categories;

- No transverse curvature of the shell
- No concave transverse curvature of the shell
- No compound curvature of the shell
- Limited compound curvature (such as can be achieved by packing the rolls) of the shell (no furnace plates)

It is toward this range of candidate simplifications that this study by Ingalls is directed.

a. scope - The areas above here considered in the decisions involved in attempting to find satisfactory lines for simplified hull forms.

1. No transverse curvature. A ship constructed without transverse curvature must necessarily feature chines and knuckles, between which the plating is either developable or somewhat twisted. This type of hull, in order to be competitive with a fair-form hull featuring compound curvature, should be model tested to align the chines with the flow in a manner so that the eddy-making portion of the residuary resistance is not excessive. Application of this type of construction to a 150,000 ton tanker brings about:

A judgement that sizeable resistance or propulsion penalties may be incurred if the lines are not model tested.

A judgement that the construction of the knuckles require a significant amount of hand work in the form of fitting plate and welding the round bars or specially shaped chine sections of scantlings.

2. No Concave Transverse Curvature
from a hydrodynamic point of view, in the stern region, lack of concave transverse curvature increases resistance far less than the lack of convex transverse curvature. Construction involving no transverse concave curvature calls for the use of flat panel intersections in a region where massive reinforcement bars (as in the case of the chine) are not

necessary. It appears that some savings can be made with this configuration in construction, without excessive hydrodynamic penalties.

3. No Compound Curvature

This type of a simplification is likely to give rise to knuckles in the longitudinal lines of the ship unless it is combined with the use of conic sections producing developable surfaces in conjunction with chines or knuckles. It is the preliminary opinion of the investigators that the hydrodynamic penalties associated with no-compound-curvature would more than offset the small construction cost savings.

4. Limited Compound Curvature

This approach to simplified hull forms is a very slight extension of current good practices. Furnaced plates are expensive so hull forms are designed so that a minimum number, or no plates-at all, require furnacing. The construction cost variations are related to the cost associated with attaining various degrees of compound curvatures, short of furnacing, by means of packing the rolls. The current trend in tanker design borders on this approach to simplified hull forms.

- b. Constraints - The major constraint in the selection of firms to be faired was an engineering judgement on the part of the naval architect involved that little if any significant increase in eddy making resistance would result from the simplifications incorporated. Verification of these good resistance qualities must necessarily be by model test, which was beyond the scope of the program.

3.2.6.2 Findings

Based on the evaluation of hull forms presently in successful use, designs for the following three bows and three sterns were developed:

- SHF-1 - Plumb bow with round bilge and square midbody bilge.
- SHF-2 - Raked bow with round bilge and square midbody bilge.
- SHF-3 - Raked bow with double chine bilge and square midbody bilge.
- SHF-4 - Straight cutup stern with round bilge and square midbody bilge.
- SHF-5 - Reverse curve stern with round bilge and square midbody bilge.
- SHF-6 - Deadrise stern with round bilge and square midbody bilge.

In addition square bilge construction detail concepts featuring round bars, square bars and angles were developed, with a range of sizes and types of weld connections to the side and bottom shell. Curves of sectional areas of deposited weld metal versus chine bar size were developed and presented.

3.2.6.3 Conclusions

Investigations regarding production cost comparisons indicate that while the square bilge is particularly cost effective in small boat construction it will not appreciably reduce production costs in large ship construction when accomplished utilizing the welding techniques applied in the study.

The possibility does exist, however, that if a specialized production line approach was applied to the manufacture of the square bilge, the full advantages of the design could be beneficially utilized to reduce production costs.

Any simplified hull forms considered for application to a design should be evaluated by model test to assure that the resistance penalty over the life of the ship is more than offset by the small savings in construction.

3.2.6.4 Recommendations

A recommended program for supplemental model testing is defined to support any future work on simplified hull forms.

3.2.7 Instructions

3.2.7.1 Approach

The development of working drawings which interpret the original ship design in terms of production information is considered to be one of the most critical support tasks affecting series production. For series production, the objective of this effort is to match or tailor the drawing content to the production process.

To achieve this objective, the preparation of the working drawings must be more closely associated with the production planning effort than is normally the case for single ship production. Reasonable additional costs which may be incurred by expansion of this effort are considered to be justified by the additional benefits which will accrue throughout the duration of the series production contract.

- d. Scope - In the development of the hull production drawings, a number of options exist regarding the level of breakdown or the boundary constraints which may be applied during development. Information on working plans can be grouped in at least four different ways as follows:

Whole Ship

In this system the ship is treated as one unit. This is the conventional method of preparing ship plans.

Modules

This system is similar to the conventional whole ship system just described but plans are prepared and grouped to suit structural modules of a length best suited to the production facilities of the building yard.

Assemblies

just as an entire hull can be made up of several structural modules, each extending the breadth and depth of the ship, so can one module be made up of several structural assemblies.

The assembly method of plan delineation and grouping involves drawing all of the structure and all pre-outfitting for each assembly on one drawing. Each structural plan will thus show the panels or subassemblies required to make up one assembly plus views showing how the panels and sub-assemblies go together to make one assembly. A small scale key plan will show the location of the assembly in the hull.

Panels

In this system the working plans consist of delineations of structural panels, one panel to each sheet. Each structural Plan shows all plates and stiffeners which make up the panel. A small scale key plan shows the location of the panel in the hull.

Piece Part Plans

Piece part plans show one structural member, plate, stiffener, bar, or other part per plan. Such drawings are obviously particularly useful in fabrication as well as in operations preceding fabrication. Minimum skill on the part of the workman is required along with minimum opportunity for error.

- b. Constraints - minimum production time and minimum engineering time combined was the goal in selecting the recommended drawing system.
- c. Analysis - Arbitrary weighing coefficients for applicable merit elements were chosen and a somewhat subjective ranking was prepared. The large magnitude of the production hours served to swing the conclusions to those which would have been derived from consideration of production alone, so that the conclusions were relatively insensitive to the arbitrary weighting factors chosen.

3.2.7.2 Findings

- a. The major portion of the fabricated steel which makes up the hull structure is assembled into sub-assemblies or assemblies only.
- b. Pipe is installed, or can be installed, at all levels of progress.
- c. Very little, if any, sheetmetal, machinery or electrical type equipment is installed at the sub-assembly level. This type of equipment is installed at the assembly level, and on through to ship completion.
- d. More material is fabricated to be installed at the assembly level than at any other level of progress in the ship construction cycle .

The indication here is that if the working plans were developed to reflect the total installation at the assembly level, they would better reflect the work content as accomplished in production,

recognizing that lower-level or piece-part drawings would be required" in order to support the assembly level plan, and that additional plans showing later installations which are accomplished after the joining of the assemblies would also be required.

3.2.7.3 Conclusions

Since assemblies become separate entities in the preferred system, there is considerable merit to consideration of an assembly plan tree. Such a tree would consist of (1) a Top Asserly Plan, (2) Hull Structural Assembly, (3) Pipe Installation, (4) Machinery Installation, (5) Electrical Installation, and (6) Sheetmetal Installation. Items (2) through (6) would completely define in detail the assembly , while (1) would define its scope. Such a plan tree would permit inspection of all aspects of the pre-outfitted assembly, and such testing as can be completed at that level.

To supplement the assembly plans, integration plans covering the definition of makeup pieces, field butts, and other parts required during ship integration would be required. These plans could then be used for inspection at the time of integration.

The recorrimended structural working plan for series production is an assembly-level drawing augmented by:

- a. Piece-part drawings as required to manufacture standard parts and parts selected for batch release.
- b. Sub-assembly drawings as required to reflect the work content at specific work stations.
- c. Panel drawings as required to support fabrication of panels prior to installation in assembly. (See "production Areas and Shops", Vol III, Part 2).

- d. Integration drawings and/or installation drawings as required to coordinate the joining of the structural assemblies and these installations which must be made after the ship is completely assembled.

The real message to be concluded from this study is that for series production, the time spent for the development of working drawings is one of the best investments which can be made by a shipyard, if the results are successful in interpreting the ship design in the simplest form required, regardless of the method utilized.

3.3 SHIP PRODUCTION PROCESS

3.3.1 Facility Utilization

For a shipyard to realize the benefits of a series production program, the manufacturing operations must be planned and executed to optimize utilization of the yards fixed facilities and their associated characteristics.

The general approach for achieving this objective is to establish a balance of required capabilities throughout the shipyard which are needed to support the production of a given series of ships. To accomplish this goal four major task items were identified which, then properly accomplished will assure a coordinated and well prepared approach to the series production program. The four major topics included in the study are:

- a. Product Design Effort
- b. Facilities Capability Manual
- c. Stationization Plan
- d. Manufacturing Plan

The Product Design Effort objective is to reduce ship production costs by increasing the comparability between the finalized ship design and the production capability of the shipyard which is slated to build the ships.

The objective of the Facility Capability Manual is to emphasize facility considerations during the design process. The Capability Manual will define the fixed characteristics of the various equipments and shops which make up the total shipyard production capability. Once this information is formalized, it can be utilized by Engineering Planning and Material Planning to influence ship design characteristics to suitable to the shipyard facilities.

The objective of the Stationization Plan is to integrate the rates and cycles of all discrete tasks anticipated for series production, thereby optimizing the use of the total resources which make up the shipyard facility. A stationization plan for the structural assembly portion for a nine ship series production contract is included.

The objective of the Manufacturing Plan is to establish a detailed plan of action which formulates the requirements generated by a specific shipbuilding contract and establishes the sequence of events in the production process as planned for the execution of that contract. A basic outline for the contents of a Manufacturing Plm applicable to a 150,000 DHT tanker is included.

3.3.2 Production Areas and Shops

In this part of the study, five structural elements of the 150,000 DWT tanker were extracted from the midship section and synthesized through the fabrication process -

1. Floors
2. Gerciers

3. Brackets
4. Small Panels
5. Large Panels

For each of these items, a single ship production run was compared with the more specialized series production method, and the respective costs were developed including the cost of the special tooling required for series production.

With the exception of the large Panel Line, the manufacturing costs as developed for these components were significantly reduced by the application of series production methods. In each of these cases, the cost of the specialized set-up and tooling was justified on the basis of a two-ship construction contract, with savings for additional follow-on ships resulting in a continuously increasing cost differential.

In contrast, while large panel fabrication represented the greatest area of potential for the reduction of direct labor costs, the substantial capital investment required to establish the Panel Shop could not be justified on a short-term basis, and must be considered a long-range facility-type investment, which would be amortized over a prolonged period of time.

There are some rather significant implications which are suggested by this part of the study:

- a. While many of the costs associated with the construction of a particular ship are essentially "fixed", meaning they will not vary a great deal from one shipyard to the other, the steel fabrication and hull costs can vary a great deal, depending on the production efficiency of the shipyard.

- b. Previous single-ship estimating baselines, such as historical data of past performance, etc., will not be applicable to series production, particularly where specialized production methods are employed.
- c. Given a series production contract of sufficient number, a shipyard may eventually realize the reduced production costs as originally anticipated. However, there is a certain amount of risk associated with projecting the pay-back points for capital improvements and special tooling, and the actual achievement of the lower production costs which were used as a basis for justification.

This part of the study is continued in the digs and Fixtures portion of the study, Volume III, Part 7, where the series production methods are extended to the platen and erection areas.

3.3.3 Work Stations

The objective of this part of the study was to examine the work station process as currently being used in non-marine and marine industries and determine the feasibility of utilizing the work station concept in series production of ships. Five major non-marine industries and three shipyards were visited by representatives of the study group for the purpose of collecting data and information relative to application of the work station concept of manufacturing. Major items of interest developed, during these visits and applicable to this part of the study, are presented by each company visited.

The most pronounced variation in operational system used by the non-marine companies visited was the application of the work station concept and the method of moving the products through the established station. The first system was based on high volume production rates

were all materials are moved through the work stations by a continuously moving conveyor. Each work station is therefore "forced efficient". Detailed pre-planning and extraordinary preventative measures are necessary to preclude work stoppages. This method of stationization appears to have very little adaptation to the shipbuilding industry.

An alternate method of work station application observed was the practice of identifying each production operation required to a facility work station and to plan and schedule all work in sequence by work station. This method of stationization can be operationally flexible and in some respects is similar to the lead craft concept of traditional shipbuilding.

The shipyards visited or contacted during the study are to some extent stationized. The method of applying work stations to shipyard operations were found to vary from casual application to completely established work stations by "design concept".

The work station concept of manufacturing as being applied in both non-marine and marine industries offers a distinct potential advantage to a shipyard contemplating series production of ships.

3.3.4 Production Planning

The development of this topic was designed to identify the unique production planning requirements which would be generated by a series production contract and to assist shipyards in accomplishing these requirements within the framework of production planning systems currently in use.

Interviews were conducted with officials of the aircraft manufacturing industries, heavy machinery manufacturers and East,

West and Gulf Coast shipyards. The interviews with non-marine industries officials were made in an effort to determine the type of production planning systems employed in these industries, the degree of their effectiveness, the level of effort and lead time devoted to production planning prior to actual start of production manufacturing and the suitability of their production planning system for adaptation to series production of ships.

Interviews were conducted at shipyards to determine the range of production planning systems currently being applied in the U.S. shipbuilding industry. Based on the information obtained a functional description of the three basic production planning systems employed by the U.S. shipbuilding industry was developed. The three systems are defined as being Lead Craft, Group and Work Package Systems. The Work Package System is presented in some detail in Volume II, Part 4.

A value comparison evaluation of the three production planning systems was accomplished, where each system was graded on its ability to satisfy series production functional objectives and considerations for the four phases of the production planning cycle. Additionally, these factors were applied to determine the value of each of the three systems when they are used for single ship production.

As a result of this comparison analysis, it was determined that the Work Package System represents the highest cost, least flexible, most complicated and most extensive system reviewed. Nevertheless, when evaluated in terms of applying series production techniques to the construction of large tankers, the Work Package System offers, by far, the greatest opportunity to ensure that economic benefits are gained by a high degree of control over the production process and through the transfer of learning where the work station concept of manufacturing is employed.

Considering the wide variation in U.S. shipyard facilities, product mix and type of labor force, the selection of a production planning system to be employed for series production has to be made largely on the basis of its suitability for a specific shipyard. However, there appears to be little doubt that a positive effort should be made by shipyarders to adopt the advanced planning features of the Work Package System outlined in the section, to the lowest level of detail as practicable.

3.3.5 Material Planning

During the investigation phase of the study, it became apparent that material planning and material support systems in U.S. shipyards vary extensively. In shipyard organization structures, the material planning and material operations functions are executed under the production department, production planning and control, or are a separate department reporting directly to the shipyard manager. In view of these organization differences as well as the many variances in the physical plants and shipbuilding programs in process, it was considered virtually impossible to develop a material planning and operational system for series production that would have practical and universal application to all shipyards. Therefore, this portion of the study was largely directed toward those areas where material planning and material application have a direct relationship to the manufacturing system and methods employed in building a series of ships. The manufacturing methods and systems developed in this study, which may affect material planning for series production center around recommendations contained in Volume 11, Part 7 and Volume III, Parts 1, 2, 3 and 4 and are enumerated below:

- a. Assembly and pre-outfitting manufacturing techniques for construction of hull modules.

- b. Machinery packaging techniques for stern module outfitting.
- c. Assembly level working plans supplemented by piece/part plans.
- d. Maximum application of the work station assembly line concept for manufacturing and assembly.

Implementation of items a. and b. for yards following conventional ship construction methods should cause only minor impact in the areas of purchasing, inventory control, inspection, etc. However, the development and application of a piece/part numbering system which will complement the objectives of assembly level working plans system and work stations/assembly line concept of manufacturing will likely require changes to current practices. Utilization of these systems are considered critical for harnessing the economics associated with assembly line and module construction methods. The identification system should provide the capability for a single piece/part to be identified in terms of (a) the engineering drawing which describes it and (b) the installation which requires it. The material identification application elements are:

Figure 5-1 in Volume III, Part 5, represents an assembly of a piece/part numbering system which may be applied during the development of the ship's plans.

The importance of developing and applying a physical numbering system to pieces, parts and subassemblies is also highly essential in

maximizing, the benefits of the work station concept of manufacturing. There are a number of marking systems which will satisfy this requirement. The following is an example of a marking system applied during fabrication, subassembly and assembly stages which will meet the requirements, including describing the item's ultimate location in the ship:

A series production contract provides the builder with an opportunity to apply mass production techniques to producing the many parts and pieces of material required. Identification of these items as early as practical during the design development phase and the piece/parts plans preparation phase is essential for maximizing the benefits from batch release manufacturing. Early identification of many of these items will allow scheduling of the work through the shops during low utilization periods of manpower and machines for regularly scheduled work, thereby maximizing the benefits of batch release manufacturing by increasing the output of the same machines and work force. Production planning personnel assigned to the engineering department for the specific purpose of identifying batch manufacturing type items, during the design development phase and piece/parts plans phase, will usually assist in expediting the preparation of the candidate list for batch manufacture material.

3.3.6 Cranes and Heavy Equipment

This portion of study is considered to be the type of information which can contribute to improved utilization of existing shipyard equipment and be useful in forecasting future heavy equipment

requirements generated by a series ship production contract. The report addresses three major subjects, each dealing with lifting or moving materials in support of ship production. The three subjects are:

- a. Crane Capacity Study
- b. Economic Use of Equipment
- c. Heavy Load Moving Systems

The Crane Capacity Study is an analysis of the degree to which the hull erection span time will be affected by variations in the maximum load which can be erected in a single lift. In an effort to develop a feel for minimum crane capacity required to support production of a 1.50,000 dead weight ton tanker and to evaluate the effects of variable crane capacities on the erection span time for a single ship, three midbody configurations were chosen from Volume 11, Part, I "Midship Configuration" of the study and used as "models" for the analysis. The study results are representative of the rationale which has been used to justify the installation of "goliath" type cranes, as is the trend in many foreign shipyards, and are included to demonstrate the type of analysis which may be applied to evaluate lift capacities in anticipation of a series production program. As mentioned in Volume III, Part 1, the "Facility Utilization" section of the study, the optimum facility is one that is "balanced" in capability throughout the production process. An increase in crane capacity would not be useful in the absence of adequate resources that are required to utilize and support the increased lift capacity. Therefore, cranes should normally be sized in accordance with the maximum projected capability of the over-all facility.

Under the subject "Economic Use of Material Handling Equipment" a comparison was made of the various options which exist in material handling equipment for lifting and moving both steel plate and

fabricated assemblies. Utilizing basic formulas, which were developed, several types of selected equipment was analyzed and compared for given sets of conditions. The selected equipment has been plotted in graph form so as to highlight the results of operational comparison under various conditions and to establish the specific points of cost effective intercept for each type of equipment and condition. Use of these charts can assist shipyards in selecting equipment which will best meet the actual shipyard conditions and result in the most cost effective method of moving materials.

Under the subject "Heavy Load Moving Systems", a summary of the results of visits to three U.S. manufacturers of such equipment are presented. These systems have been developed in recent years and represent systems whereby structures ranging from 400 tons to several thousand tons may be moved horizontally for distances commensurate with shipbuilding requirements for assembly, integration and launch. The suggested advantages of a Heavy Load Movement System are lower initial cost in comparison to cranes with greater logistic flexibility.

3.3.7 Jigs and Fixtures

While jigs and fixtures have been recognized as a significant contributor to reduced production costs in shipbuilding, their development is often left to the crafts and their implementation is often regarded as a "bonus", or some part of the learning process, rather than a pre-planned technique which must be executed in order to achieve the objectives of a pre-established manufacturing plan.

In reviewing the non-marine industries and the emphasis placed on this facet of the manufacturing process, it is surprising to see the parallels in the production process which exist between these industries and shipbuilding. In terms of potential, the benefits

derived in non-marine industries represent an important area for further development in shipbuilding and the only reason which can be found for the current state accomplishment in shipbuilding is the lack of opportunity and minimal emphasis placed on the subject.

When judged within the shipbuilding environment of fast-changing relatively short-term objectives, these conditions are understandable, so long as every effort is made to expand and improve the use of jigs and fixtures with each opportunity for series ship production.

With this goal in mind, an innerbottom section of the 150,000 DWT tanker was used as a basis for jig and fixture application in the assembly area, resulting in a reduction of span time as well as a manhour savings for the assembly of the subject unit. Expansion of this application to suit a total ship production schedule would increase the benefits proportionately, and could effect the capacity, or number of ships which could be built, within the constraints of a specific shipyard facility.

3.3.8 Machines

This part of the study emphasizes the application of machines to series production of ships as a means of reducing manpower requirements used accelerating production rates.

A number of different types of machines which have application to ship production and possess a potential of increasing production were investigated. A selected number of these machines which have considerable merit for reducing costs in series production of ships are evaluated in some detail, particular emphasis has been placed on those machines which abilities for converting raw materials (steel Plate and shapes pipe, sheetmetal) into finished parts at a high

rate of speed and minimum manpower requirements. Included in part 8 are evaluations and descriptions of the following type machines:

- a. Machinery for fabrication of T and L shapes
- b. Semi-automatic pipe welding machine
- c. Pipe cutting and beveling machinery
- d. Sheet metal fabrication machinery

In order to attain maximum economic benefits through series production contracts for ships there is a great need at most U.S. shipyards for modernizing shop methods and acquiring entirely new high production system equipment or modification of existing equipment which will increase productivity and reduce labor costs. In recognition that adequate capital is not always available to accomplish total modernization programs, an alternate solution for some shipyards may be to sub-contract out requirements for high use items to companies that specialize in manufacture of certain items (sheet metal, ducting, pipe hangers and clamps, sheetmetal parts in the flat pattern, electrical keel pipes, manhole covers, collars, etc.).

VOLUME I

PART 4

DISCUSSION OF INTERACTIONS BETWEEN
DESIGN AND PRODUCTION

VOLUME I
PART 4
DISCUSSION OF INTERACTIONS BETWEEN SHIP DESIGN
AND SHIP PRODUCTION ACTIVITIES

4.1 Introduction

Volumes II and III address the dependent conclusions and recommendations arrived at by considering each topic as an individual subject with its own optimization. Important inter-relationships are alluded to but not fully developed in these volumes. It was felt that a misleading picture would be developed if these inter-relationships were not more thoroughly explored.

4.2 Methodology for Organizing Inter-relationships

The matrix of all the ship design and ship production topics was prepared. This matrix listed all the topics as headings for rows and the same topics in the same sequence as headings for columns. The titles for the rows were then assigned as primary or independent variables while the same titles for the columns were considered as secondary or dependent variables. The first iteration of this procedure treated the subjects in the sequence in which they are called out in the index. Each row was treated by considering each square in terms of the effect of the independent variable on the dependent variables. These effects varied from zero or negligible to a well-defined impact or series of impacts. Obviously the diagonal of such a matrix is the effect of a variable on itself and therefore is not zero or negligible. A summary matrix was then prepared from the completely filled out matrix in which any square that represented an influence was marked with an "X".

Examination of this matrix revealed that (1) there was a logical break between design and production, (2) that a resequencing of the designing functions into contract and detail design and the production functions into planning and manufacturing was more meaningful, (3) the region below and to the left of the diagonal could be characterized as a feedback area while the region above and to the right of the diagonal could be called an impact area, and (4) that there is some overlap between contract design and detail design, as well as overlap between detail design and planning,

4.2.1 Specific Sequencing of Design Activities

Simplified Hull Forms and Constant Principle Discussions followed by Mid-ship Section Configuration, all logically fall into the contract design activity. Arranging them in that order permits Mid-ship Section Configuration to also fall in the detail design activity along with Structural Member Configuration, Machinery Systems Modules and Instructions, again in that order.

4.2.2 Specific Sequence of Production Activities

Facility Utilization followed by Production Planning and Material Planning constitute the traditional planning activities associated with production which have been emphasized for series production. There is considerable merit in considering Instructions as a transition into planning, or the input material for planning. As such it falls in the overlap between design and production. Under the heading of manufacture, particularly in the context of the work package assignment concept, Work Stations followed by Production Areas and Shops, dies and Fixtures, Machines, and Cranes and Heavy Equipment logically fall into place. Material Planning, in terms of the aspect of delivering material to the work stations, would suggest an overlap with the planning activity.

4.2.3 Essential Features of Sequenced Matrix

The matrix sequenced in this fashion is shown in figure 4-1. This matrix is characterized by four blocks along the designated sub-matrices entitled Contract Design, Detail Design, Planning and Manufacturing, each one overlapping the preceding one by one row and one column (see figure 4-2). The area to the left of Manufacturing and below Planning can be referred to as the "Planning Feedback Region" while the area to the left of the Planning Feedback Region and below the Detail Design area can be called the "Detail Design Feedback Region". In similar manner the area to the left of the Detail Design Feedback Region and below the Contract Design . Region can be called the "Contract Design Feedback Region." The areas to the right of and above the Contract Design, Detail Design, Planning and Manufacturing squares or sub-matrices should be called the "Impact Region." The Impact Region is seen to be that region in which actions which are undertaken early have influences on subsequent activities. The feedback regions are regions which constitute considerations of subsequent activities to be factored into activities which are conducted early. Specifics as revealed by this pattern will be discussed in detail in sections 4.3 and 4.4.

4.3 SPECIFIC IMPACTS OF SHIP DESIGN FACTORS ON SHIP PRODUCTION

4.3.1 Simplified Hull Forms

Facility utilization is impacted for a given design in terms of the relationship between dimensions and facility arrangements, as well as the facility limitation on weight handling. Production Planning is influenced only in terms of the manpower distribution in the area of shaping and rolling plates or the lack of this operation in the case of a simplified hull form. There appears to be no measurable impact on Material Planning as a function. Work Stations will be somewhat modified to suit the configuration of the mid-ship section

though this impact should be small. Production Areas and Shops should be unaffected. Digs and Fixtures may be modified to suit the bilge configuration. There should be no impact on Machines or Cranes and Heavy Equipment.

4.3.2 Constant Principle Dimensions

Facility utilization can be improved if the decision to utilize a standard ship, stretched, or shrunk, can be sold to the customer. This allows the utilization of existing facilities to a greater extent if the design has the same basic beam and depth and mid-ship characteristics as a previously built design; that is, it can enhance the benefits of commonality between production runs. Production planning may be influenced by the changes in module breaks. In general, the advantages in facility utilization extend into Material Planning, Work Stations, Production Areas and shops, Oigs and Fixtures, Machines, and Cranes and Heavy Equipment, in that the commonality with previous production runs can be exploited.

4.3.3 Mid-Ship Section Configuration

The Mid-Ship Section Configuration will definitely influence the facility utilization in terms of the degree to which it can be set up for series production. There is a reciprocity} between these two factors which will be addressed in the feedback Section 3.2.3. Production Planning is definitely affected by the complexity or simplicity of the Mid-Ship Section Configuration chosen, as is Materiel Planning. Work Stations will be significantly influenced **by the element configurations characteristics of the Mid-Ship Section and the degree of standardization attainable and the modularization** aspects of the breakdown of the structure. The same factors will influence Production Areas and Shops, oigs and Fixtures, and Nachines. Cranes and Heavy Equipment will be influenced by the weight and the size of the assemblies and the height of lifts associated with the Mid-Ship Section Configuration.

4.3.4 Structural Member Configuration

The type of stiffeners (inverted angle or tee, purchased, stripped or built up) will have a significant reciprocal relationship with the facility utilization factor. The types dictated by the design will heavily influence the degree of facility utilization.

Production Planning is impacted by the time and manpower allocations to make the structural shapes. The Material Planning is influenced by the procurement considerations such as make or buy and distribution to the Work Stations. The Work Stations are designed to suit the fabrication methods indicated by the structural members as are the Production Areas and Shops. Machines could be influenced in terms of additional requirements generated. No impact on jigs and Fixtures or Cranes and Heavy Equipment is anticipated.

4.3.5 Machinery System Modules

A reciprocity relationship exists between Machinery System Modules and facility utilization. Though the Feedback influence should be stronger than the impact on the facility utilization; that is to **say, the arrangements developed during the design should take** advantage of the existing facilities in general. Only in isolated cases would it be desirable to modify the facilities for a specific arrangement. The Production Planning function is significantly influenced in terms of pre-outfitting, earlier tests on piping and earlier alignment. activities. The size and weight of the outfitted assemblies must be studied. Material Planning is influenced in terms of necessary lead time for any packaged units, particularly on the first ship. The ability to procure packaged units and to pre outfit will have a significant effect on the stern span, as this module is a critical path in the ship construction. Work Stations and Production Areas and Shops may be impacted if assemblies move from a hull structures environment into a machinery outfit environment and then back again into hull integration. Oigs and Fixtures may be impacted by pre-outfitting and early alignment considerations

in the shops. Machines probably will not be significantly impacted. Cranes and Heavy Equipment impacts would arise out of decisions made in Production Planning if increased capacities appeared necessary.

4.3.6 Instructions

There is no impact on facility utilization. Production Planning is directly coupled with Instructions in terms of the form and type of data contained in the instructions, and there should be a strong reciprocal relationship. In a similar manner, Material Planning will feel a reciprocal relationship relative to the numbering system for plans and piece/parts. This is particularly true of those piece/parts which are repetitive in material and made in large quantities for the parallel body part of the structure. Work Stations, Production Areas and Shops, Jigs and Fixtures, and Machines will all be impacted by those aspects of Production Planning which relate to Instructions. There should be negligible impact on Cranes and Heavy Equipment.

4.4 Specific Feedback from Ship Production

The following paragraphs will address feedback influences on the various design and planning activities.

4.4.1 Feedback to Planning

The Planning activities are defined as Instructions, Facility Utilization, Production Planning and Material Planning. (See figure 4-2)

4.4.1.1 Production Feedback to Instructions

The Instructions must be compatible with the Production Planning System, which in turn defines the basic way in which the shipyard is utilized. Elements of the Production Planning System which are impacted are (1) the Work Station concept, (2) the Top Assembly

Drawing concept, (3) the Part Numbering Concept, (4) the Maximum Preoutfitting concept and (5) the Work Package concept. This means that the information prepared by engineering translating the design into paper from which the ship can be built and parts of it bought, must. be consistent with the use to which the paper will be put. For these types of reasons, Instructions is functionally inseparable from the rest of the Planning function even though it is done in the engineering department by people whose skills are oriented toward lifting these types of information from technical engineering documents.

4.4.1.2 Facility Utilization

Efficient Facility Utilization requires the existence of a plan to utilize the existing facilities in a shipyard and with a goal of a high degree of accomplishing the job within existing facilities. For any particular program there may be the necessity for additional facilities requiring capital investments. The plan to utilize the facilities requires a detailed knowledge of the constraints and capabilities of the existing facilities so that they can be compared to shipyard master plan and its contributing program manufacturing plans which in turn are composed of a carefully time-phased overlay of individual ship manufacturing plans. The vehicle which is proposed to consolidate this information is a Facilities Capability Manual which will summarize the make-up of the Work Stations, Production Areas and Shops, Machines and Cranes and Heavy Equipment. Existing Jigs and Fixtures which can be modified from previous programs may also be included.

4.1.3 Production Planning

The capabilities and numbers of facilities in the Facilities Capabilities Manual form a basis for Production Planning's implementation of the Program Manufacturing Plan as was shown in the

previous program relates to the Work Stations, Production Areas and Shops, Machines and Cranes and Heavy Equipment. Existing Jigs and Fixtures will also be considered in this planning activity.

4.1.4 Material Planning

In a stationized yard with well defined production lines, the Material Planning will be heavily influenced by the necessity to deliver materials and in-process sub-assemblies to the Work Stations, Production Areas and Shops and Machines. Some of this delivery will be related to Cranes and Heavy Equipment capabilities, particularly in the case of sub-contracted assemblies and propulsion machinery parts.

4.4.2 Feedback to Detail Design

Specific aspects of Planning and Manufacturing should be considered in detail design preparation in order to maximize the efficiency of a series production program. (See figure 4-2)

4.4.2.1 Mid-Ship Section Configuration

Facilities Utilization factors relating to Cranes and Heavy Equipment will have a significant effect on the location of erection butts in the Mid-ship Section Configuration based upon the lift capabilities. The types of machines available in the shipyard will influence the economics of the stiffeners utilized for longitudinal framing girder stiffening. The comparison between plate and bracketed transverse frames is significantly influenced by the existence of Machines and Work Stations to process the two different types of transverse framing.

4.4.2.2 Structural Member Configuration

The available facilities will have a significant constraint on the types of structural shapes which can be economically worked into the ship. The decision to make or buy will be dependent upon the

machines available to handle this type of quantity production. In a similar manner, Material Planning and its attendant distribution function will have an influence upon whether the structural members in this category are batch released in large or small batches. A trade-off between the economics of production and the cost of material handling are implied in this area.

4.4.2.3 Machinery System Modules

Facility Utilization factors will heavily influence the degree to which pre-outfitting of assemblies will be possible and at what stage of manufacturing this pre-outfitting should occur. Cranes and Heavy Equipment will define the size of the pre-outfitted assembly and to a considerable extent influence the content of the assembly. Work Stations and Production Areas and Shops may become significantly inter-related with this phase of design in that the flow of the Machinery system Modules from a structural erection area into a machinery outfitting environment (shop) for outfitting, inspection and test, and then back to a structural integration area would appear to be highly desirable. The degree to which this is attainable in any given shipyard should influence how far the Structural Member Configuration design goals can be implemented.

4.4.2.4 Instructions

While this subject was addressed under 3.2.3.1(a) in the general area of planning, there are a number of aspects of this activity which relate to the Detail Design phase as well. In particular, the translation of engineering drawings to support planning will require that the engineering drawing format and content support the Instructions which in 5.2.3.1(a) have been shown to be of necessity compatible with the Manufacturing Planning.

4.4.3 Feedback to Contract Design

The feedback to Contract Design is mainly of a more general nature. There is a relatively strong coupling with Detail Design. The vehicle for coupling with Planning and Manufacturing is mainly through the Facility Utilization factor, specifically a Facility Capability Manual or its equivalent. This allows the negotiations with the owner and the Contract Design phase to be slanted toward a ship which can be readily built in the shipyard (See figure 4-1).

4.4.3.1 Simplified Hull Forms

The manufacturing factors which would influence Simplified Hull Forms are contained almost totally in the Facility Utilization factor. These would cover the length, beam and depth considerations of a ship which can be built in the yard. The negative consideration is the elimination of the need to utilize any plate forming equipment in some of the simple hull forms configurations which have been investigated. The remaining considerations influencing Simplified Hull Forms are of an engineering nature. There is a minor technical coupling, in that certain Simplified Hull Form Configuration will more easily contain a given machinery arrangement than others will. Details of the framing of Simplified Hull Forms may also be impacted by the machinery arrangements in the stern module. Structural Member Configuration would be a negligible interaction.

4.4.3.2 Constant Principal Dimensions

The determination of the Constant Principal Dimension aspects of a ship which can be built in a given shipyard can be arrived at by the Facilities Capabilities Manual designation of the constraints and capabilities of that yard. There may be a significant motivation to build a ship as defined in the Constant Principal Dimension concept in that production planning is also eased through the use of standardized parallel body assemblies.

4.4.3.3 Mid-Ship Section Configuration

The Facility Utilization factors which influence Mid-ship Section Configuration during Contract Design are the Crane and Heavy Equipment capacities and lift heights as well as the layout of the ship integration areas in the shipyard. These will serve to constrain the lengthy beam and depth of the ship and may influence negotiations with a prospective customer.

4.4.4 Critique of Feedback Pattern as it Relates to Series Production

Examination of figure 4-1 indicates a high density of feedback coupling from manufacturing considerations in the "Planning Feedback Region." This is necessary (and expected) so that manufacturing can proceed according to a well conceived plan. This situation will be found in any successful manufacturing activity.

A lesser, but still high density of feedback factor from manufacturing activities appears in the "Detail Design Feedback Region." This is a necessary condition for efficient series production. A lack of feedback in this area can readily occur because of the difference in point of view of the design group and the manufacturing personnel.

Such a weakening of the feedback coupling can lead to serious inefficiencies and waste motion. Similarly, there are a significant number of feedback points from the planning activity into the "Detail Design Feedback Region."

The "Contract Design Feedback Region," however, is nearly devoid of inputs from production. The only inputs of any significance are those arising through the expression of manufacturing constraints and capacities contained in the Facility Capability Manual or its equivalent. Lack of this feedback function can again result in problems in attaining a high degree of effectiveness in negotiations with the potential owner or customer. In the case of a shipyard

utilizing a contract design prepared by a design agent, this Facility Utilization Manual or its equivalent becomes a vital necessity to prevent aspects of the contract design becoming firm which will subsequently require extensive and expensive facility improvement once the contract is in hand.

4.5 Proposed Improved Feedback Mechanism

Shipyards which perform their own detail design will have recognized the need for close coordination between the engineering function and the preliminary and firm manufacturing plans. Organizational procedures will have been structured to ensure that the information is available to the designer.

In the case of the outside design agent, this flow of information relative to the essential features may be lacking, or at best, fragmentary. Transmittal of the preliminary manufacturing plan to the design agent, and the maintenance of an active shipyard industrial engineer at the design agent office during the design can help to correct this deficiency.

Major items of concern in this vein are:

a. Butt and seam locations of shell, bulkheads and decks to suit:

- (1) erection of assemblies
- (2) shipyard welding practices and equipment

b. The types of transvers framing webs to suit any specialized bracket and beam production lines, or lack thereof.

These and similar considerations will impact both contract design and detail design for producibility.

Figure 4-1. Interaction Matrix (Sheet 1 of 2)

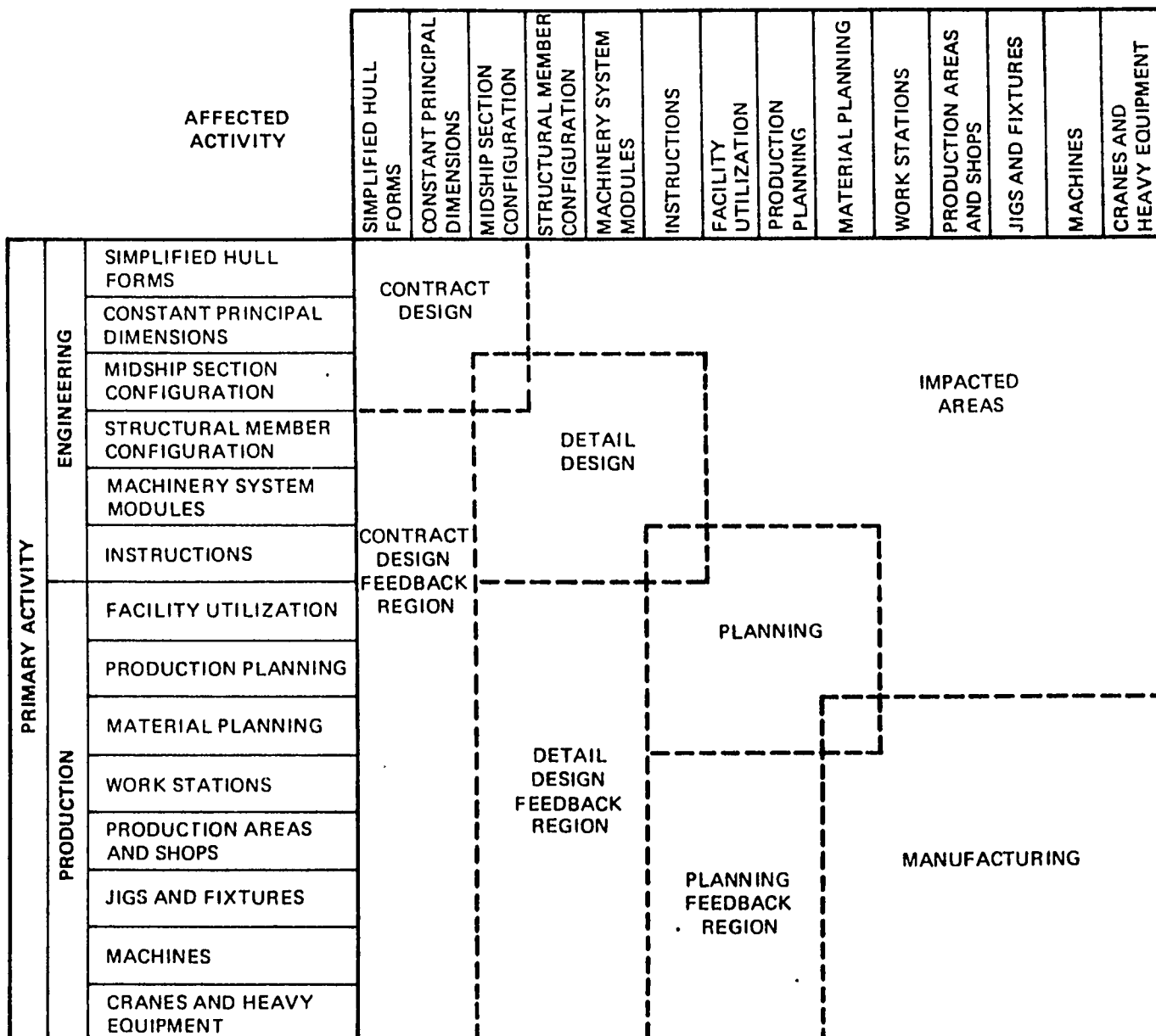
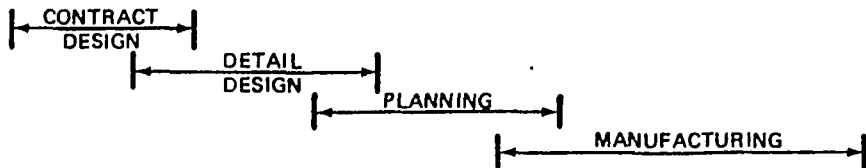


Figure 4-1. Interaction Matrix (Sheet 2 of 2)

PRIMARY ACTIVITY	AFFECTED ACTIVITY														
		SIMPLIFIED HULL FORMS	CONSTANT PRINCIPAL DIMENSIONS	MIDSHIP SECTION CONFIGURATION	STRUCTURAL MEMBER CONFIGURATION	MACHINERY SYSTEM MODULES	INSTRUCTIONS	FACILITY UTILIZATION	PRODUCTION PLANNING	MATERIAL PLANNING	WORK STATIONS	PRODUCTION AREAS AND SHOPS	JIGS AND FIXTURES	MACHINES	CRANES AND HEAVY EQUIPMENT
ENGINEERING	SIMPLIFIED HULL FORMS	☒		X		X	X	X	X						
	CONSTANT PRINCIPAL DIMENSIONS		☒		X			X	X						X
	MIDSHIP SECTION CONFIGURATION	X		☒	X			X	X	X	X	X	X	X	X
	STRUCTURAL MEMBER CONFIGURATION	X		X	☒	X	X	X	X	X	X			X	
	MACHINERY SYSTEM MODULES	X				☒	X	X	X	X	X	X	X		X
	INSTRUCTIONS					X	☒		X	X	X	X	X		
	FACILITY UTILIZATION	X	X	X	X	X	X	☒	X	X	X	X	X	X	X
	PRODUCTION PLANNING			X		X	X	X	☒	X	X		X		X
	MATERIAL PLANNING				X	X	X			☒	X	X		X	X
	WORK STATIONS			X	X	X	X	X	X	X	☒	X	X	X	X
PRODUCTION	PRODUCTION AREAS AND SHOPS					X	X	X	X	X	X	☒	X	X	X
	JIGS AND FIXTURES				X	X	X	X	X		X	X	☒		X
	MACHINES			X	X	X	X	X	X	X	X	X		☒	X
	CRANES AND HEAVY EQUIPMENT			X		X	X	X	X	X	X	X	X	X	☒



VOLUME I
PART 5
PROGRAM CONCLUSIONS AND RECOMENDATIONS

VOLUME I
PART 5
PROGRAM COLLUSIONS AND RECOMMENDATIONS

5.1 Introduction

Conclusions expressed in this section are those of the investigators relative to the whole process of series production of ships. They represent observations relative to what is good for, or bad for, or pertinent to this whole approach of integrated repetitive mass production of a single type of ship. These conclusions may be in variance with conclusions reached in sub-sections which represent specific sub optimizations of each topic discussed.

5.2 General Overall Observations

5.2.1 The concepts discussed and developed in this program are, in general, not new. It was found that, in the marine industry, there is at least one shipyard practicing or developing each concept included in the study. On the other hand, there was no shipyard organization which was practicing, in a highly developed form, all of the concepts discussed and developed herein.

Those other industries outside of the marine industry which were visited had developed some of the concepts beyond a point applicable to the marine production problem because of their high volume rate and length of production run, but in many cases there were beneficial concepts discovered during the visits.

5.2.2 A clear cut understanding of the functions in the contract design, detail design, planning, and production chain which require development and emphasis will help in assessing the areas which require upgrading for series production in any given shipyard.

Organizational changes will then follow logically, only limited in rate by the ability of the personnel to accept changes without confusion.

The major message is that design activities, especially detail design, be tailored in terms of their output, so that it supplies and supports planning, and production with maximum efficiency and minimum waste motion in planning and production. Extensive liaison during design on the part of material, planning, and facility personnel is vital, especially if a design agent, not co-located, performs the detail design. Standards describing facilities, clearances for processes, slip dimensions, shop capacities, etc., are invaluable to supplement this liaison.

- 5.2.3 There has been a preoccupation with the steel hanging aspects of series production in the past, which has heavily influenced this study. It is observed that, until comparable advances are made in the methodology of outfitting (or pre-outfitting) machinery, electrical, piping and joiner work in the stern module, both its cost and construction span time will prohibit full realization of the potential savings indicated in this study.

Further studies should investigate this aspect of the problem, which is compounded by the fact that it crosses trade boundaries in the shipyard.

- 5.2.4 As the study progressed there was a strong indication that for successful and effective mass production of ships, an extensive

subcontracting program should be initiated for the following reasons:

- (1) With one or two exceptions, no existing U.S. shipyard has the acreage and terrain to permit extended assembly lines and expansion of production shops that would be required to support mass production at a high rate of 150,000 dwt crude carriers.
- (2) The skilled craftsmen in the numbers and varieties of skills required, are not currently available in any one geographic region.

By subcontracting, certain parts and systems could be assigned to diverse regions where specific skills or specialized equipment is readily available, and a certain amount of experience has already been developed.

5.3 Specific Conclusions Related to Functions and Organizations
Conclusions expressed in this section are in context with an ideal series production program. Some shipyards approach it, but none practice it across the board.

5.3.1 Contract Design
Contrary to the assumed starting posture for Constant Principal Dimensions, the conclusion reached is that the ship should be designed for the capacity and route, and in the current scheme of costs, small savings for acquisition costs are more than offset by resistance penalties incurred by non-optimum stretched or shrunk forms, i.e. 180,000 dwt and 120,000 dwt derivatives of 150,000 dwt design.

The midship section chosen for the design should reflect the yard's least expensive fabrication choice.

Simplified hull forms do not appear to be justified (hard knuckle shapes) because (1) construction savings are miniscule or non-existent, and (2) resistance penalties may be incurred, increasing operating costs. Non-recurrent model testing costs will be incurred to ensure that there are no such penalties.

5.3.2 Detail Design

Specification of shell, bulkhead and deck longitudinal (built up for 150,000 dwt ships) to suit machines and work stations to be used in the yard will result in a balanced design easy to build.

Development of three or four standardized power plant arrangements of comparable performance to satisfy owner preference seems feasible, with little impact on basic stern structure. Care to arrange auxiliary systems to be mounted on assemblies without crossing assembly field butts can bring about savings in pre-outfitting and pre-testing.

Instructions designed to interface well with planning and production will pay dividends in lack of waste motion and redundancy. Plans prepared by assembly (top assembly drawing with tree branching into structure, piping, machinery, electrical, etc.) will permit construction and inspection of assemblies and will feed planning work package software well.

5.3.3 Planning, Production and Material

Strong centralized planning to in depth level of detail is necessary for efficient series production. Of those systems examined the Work Package System is the most detailed planning system investigated, and represents a strong effort to establish and locate most production planning outside of the production directorate. It is a system of high control, with an inherent capability for refined

scheduling, statusing and cost monitoring on a sustained basis throughout a multi-ship contract. The elements of the Work Package can be organized to suit the user of the planning information as required to support specific machine loading or manpower requirements, etc.

The production planning effort at most shipyards should be expanded for series production for large crude carriers regardless of the system which is presently utilized for conventional shipbuilding. Since both the engineering and planning efforts are essentially accomplished once for a given ship type, these efforts can be justifiably expanded for series production, since the greater manhour expenditure can be amortized against a multi-ship contract. The benefits gained by this additional one-time effort should accrue on each ship to be built, with a net reduction in the cost for each ship of the total series.

Additional consideration should be given to the following areas:

- (1) Material identification to the piece/part level and movement of material by this identification method through the work station concept of manufacturing and
- (2) Application of batch release manufacturing techniques to mass production of many like items.

A series production contract for large tankers provides the builder with the opportunity to apply mass production techniques to the manufacturing of many of the pieces and parts required. The design features of a tanker allows sizeable multiple applications of a variety of items used in construction of this type ship. Repetitive use components which have a high population count are in the hull, pipe, ventilation and electrical disciplines.

5.3.4 Production

The work station concept is widely used in series production in the non-marine industries, but in varying degrees is currently being applied to shipbuilding and in two instances with a marked measure of success. In the non-marine field the work station concept is applied by one of two different methods.

1. The in-line continuously moving conveyor that moves the product through all stations at a predetermined speed and with predictable results. This method and/or concept is used primarily by the high volume high production rate facilities, and with the exception of instances where automated machines are used in shops, is far too complex and the prerequisites for production is cost prohibitive for shipbuilding.
2. The second method of work application is used to full advantage by the non-marine industries that produce the heavier and larger products (i.e. 160-ton locomotives; off-the-road trucks). This method consists of the use of numerically identified work stations located geographically by function throughout an entire facility. The sequential operations are planned by work stations, but the means of movement is by crane, wheeled dolly, or by the most cost effective method available. The application differs also inasmuch as it is flexible as to the sequencing of products through each station. This concept allows the production line to be "station efficient" as opposed to "forced efficient" as is the first method described. The results of the evaluation indicate that this method of utilizing work stations offers a distinct potential advantage to series production of ships.

A corollary to the Work Stations concept is the enhanced use of jigs and fixtures, with inherent savings. The break even points for many

fixtures studies is such that they have paid for themselves in as few as one or two ships.

Similarly, in the study of Production Areas and Shops, it was found that lines for small panels, brackets, girders, and floors paid for themselves in the first few ships.

The use of specialized semi- and fully automatic machines produced similar payoffs, with the additional benefit that they can be operated efficiently by employees with less skill and training than is required for the manual methods.

Recent developments in load moving equipments with capacities up to 1000 tons or so have made equipment available whose budgetary costs run per ton of lift-move capacity in the range from \$50 to \$150 as compared to cranes in 200 to 800 ton capacity costing from \$12,000 to \$20,000 per ton of capacity.